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Developing sustainable building assessment scheme for Saudi Arabia: Delphi consultation approach

Saleh. H. Alyami [a,*], Yacine Rezgui [b,1], Alan Kwan [c,2]

[a] School of Engineering, Cardiff University, UK
[b] BRE Institute in Sustainable Engineering, School of Engineering, Cardiff University, UK
[c] Architectural, Civil and Civil & Environment Discipline, School of Engineering, Cardiff University, UK

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ABSTRACT

Scientific evidence suggests important discrepancies between simulated and real energy performance of buildings. This is exacerbated in developing countries, such as Saudi Arabia, by the reliance on leading international building environmental and sustainability assessment schemes (e.g. BREEAM and LEED). The paper proposes to test the overarching hypothesis that the leading international environmental and sustainability assessment schemes are not adapted to the Saudi built environment, with a focus on the residential sector. The paper aims to (a) test the applicability of international leading schemes such as BREEAM and LEED for the assessment of Saudi's built environment, and (b) identify applicable building assessment categories and criteria for Saudi's built environment. As building assessment methods involve multi-dimensional criteria, a consensus based approach is used to conduct the research. Hence, the Delphi technique is selected and conducted in three successive consultation rounds involving world leading experts in the domain of environmental and sustainable assessment schemes, as well as professionals and highly-informed local experts from academia, government and industry. The results reveal that international assessment schemes are not fully applicable to the Saudi built environment, as reflected in the development of a new building environmental and sustainability assessment scheme.

Contents

* Corresponding author. Tel.: +44 77155 86 979; fax: +442920874716.
E-mail addresses: dr.saleh.uk@gmail.com (Saleh.H. Alyami), RezguiY@cardiff.ac.uk (Y. Rezgui), kwan@cardiff.ac.uk (A. Kwan).
[1] Tel.: +44 29 2087 5719; fax: +442920874716.
[2] Tel.: +44 29 2087 6834; fax: +442920874716.

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1. Introduction

In Saudi Arabia, the climatic conditions, topography and limited water supply hinder the organic development of communities, neighbourhoods, and cities [1]. However, since escalating economic growth in the early 1970s from the oil boom, living patterns have substantially changed toward the adoption of modern, luxurious, and energy demanding lifestyles [1–3]. The building industry in Saudi Arabia has undergone major development [4]. The principles of vernacular architecture, emphasising the utilisation of local building materials and low-energy use, have been replaced by more modern building interventions. Hence, the traditional mud and stone-based buildings have been widely replaced by reinforced concrete frame structures, combined with modern architectural styles that use a wide range of building components, including large windows [2,5,6].

However, current conventional building construction and operation practices consume excessive levels of resources and severely impact on the environment, at a level that is not sustainable [7]. To put this assertion into perspective, the electricity total peak load in 1975 was only 300 MW, increasing to 34,953 MW by 2007. Current projections predict that the electricity total peak would reach 57,808 MW by 2023[8].

The building industry has one of the highest adverse impacts on the natural environment [9]. The consequences of climate change and global warming are putting increasing pressure on all nations to implement strategic methods for enhancing the sustainability of the built environment, whilst protecting their natural resources [10,11]. Hence, the strategic importance of environmental and sustainable assessment schemes [12].

Therefore, over the past decade, a number of different building environmental and sustainable assessment schemes have emerged in the developed world for the promotion of sustainable building interventions [13–18]. BREEAM (*Building Research Establishment Environmental Assessment Method*) is one of the first assessment methods, launched in the early 1990s by the Building Research Establishment in the UK [19,20]. Subsequently, a number of sustainable assessment schemes have been developed and adopted in other countries, including LEED (*Leadership in Energy and Environmental Design*) [21], SBTool (*Sustainable Building tool*) [22]. and CASBEE (*Comprehensive Assessment System for Built Environment Efficiency*) [23]. All of these assessment schemes share the same primary objective of stimulating the market demand for buildings with improved environmental performance [13–18].

The paper aims to (a) test the applicability of international leading schemes such as BREEAM and LEED for the assessment of Saudi's built environment, and (b) identify applicable building assessment categories and criteria. Particular attention will be given to the residential sector, as it is the largest consumer of natural resources [1]. Following this introduction, the methodology that underpins the research is presented, supported by related work that informed the development of the initial building environmental assessment theoretical model. An in-depth description of the Delphi consultation is then given, followed by a discussion of the resulting building environmental assessment scheme adapted to the Saudi environment. Concluding remarks and planned future work are then given.

2. Research methodology

The overarching hypothesis of this study is that *the leading environmental assessment models currently in use, such as BREEAM and LEED, are not adapted to the political, environmental and social specificities of the Saudi built environment*. This is in recognition of regional variations, including the constraints of available resources, local architecture, specific environmental conditions, and other economic and socio-cultural factors. The research is underpinned by the following research question: *what are the required categories and criteria that form the best environmental assessment method for the Saudi Arabian built environment*?

Cole [39] argues that the starting point for the development of a potential new scheme should be a comparative study of well-known assessment schemes. Hence, this study analyzes the most important and globally prevalent environmental assessment methods: BREEAM, LEED, SBTool, and CASBEE [24,25]; in order to determine key similarities and differences between their underlying approaches, thereby establishing the basis for potential sustainable categories and criteria for a new Saudi Arabian scheme.

As environmental and sustainable building assessment criteria are generally considered to be multi-dimensional [17], scientific evidence suggests that a consensus based approach is best suited for the development of a comprehensive and effective building environmental assessment schemes [26]. For this reason, the chosen research instrument in this study is the Delphi technique. This approach consists of an anonymous and multi-stage survey. Feedback of group opinion is gathered after each round, with the goal of achieving consensus on certain criteria [27–29].

Currently, the Delphi technique is used as a research instrument within fields as diverse as engineering, policy making, as well as sustainable development [29–32]. More recent applications of the Delphi technique have relied on web-based consultations [33]. The key stages of the Delphi technique within this study are: Selection of the Delphi panel, the development of Delphi questionnaires, Data collection process, and Data analysis.

3. Related work and theoretical model development

Construction activities have a significant impact on natural resources, which in turn affect our built environment, the economy and society at large. Over the last couple of decades, environmental assessment methods emerged as a yardstick for sustainable practice in the built environment [12]. Since the 1990s,

a number of various systems have gained large scale acceptance. BREEAM, for instance, was used as a guide for the development of similar schemes in different parts of the world, including New Zealand, Norway, Canada and Singapore. LEED enjoys many registered projects around the world, including India, China, Canada, Brazil, and Mexico [34]. These two environmental assessment systems are widely considered as market leading methods: BREEAM has over 250,000 certified buildings and over 40,000 projects registered for certification [20]. Further, LEED has 10 billion square feet of space certified under LEED schemes [21].

Cole [35] provides an interesting insight into environmental assessment methods arguing they should act as a tool for (a) stimulating market demand for buildings with sustainable or green performance, (b) keeping decision-makers informed during building design, and (c) delivering evaluative dimensions of a building's impact on the ecosystem. More recent literature suggests that the general scope of these systems should include: (a) energy efficiency design, (b) pollution & CO_2 mitigation, (c) natural resource management, and (d) human health and wellbeing [36,37]. Ding [73] states that environmental assessment methods play an important role in raising awareness of building practices and their consequences for the environment. Moreover, they (environmental assessment methods) pave the way for increased environmental protection and sustainability development.

Despite environmental assessment methods' significant contribution towards understanding the relationship between buildings and their environment, existing methods still face many criticisms [19]. Financial aspects, regional and cultural variations are amongst the most debated areas. Ding [73] states that existing methods, such as BREEAM, LEED, and HK-BEAM, focus on a set of environmental aspects (energy, material, water, indoor comfort etc.), but they do not include financial considerations in their schemes. This, in turn, may contradict the ultimate principle of sustainability, as financial returns and economic aspects are considered as prerequisite for effective sustainable development. Furthermore, Cole [14] states that it is scientifically wrong to use environmental criteria that were originally designed for a specific region and promote their adoption across other regions of the world. This means that building categories and criteria should be customised and prioritised to reflect regional conditions.

Various related studies have been carried out to adapt building assessment criteria, to suit local conditions and, in turn, overcome regional adoption obstacles. For instance, Chang et al. [38] conducted a study to adapt SBTool in Taiwan. They utilised Analytical Hierarchy Process (AHP), aiming to prioritise environmental and regional dimensions to suit Taiwan local conditions. Furthermore, Lee and Burnett [18] state that in Hong Kong, there has been increasing public demand for the development of sustainable buildings. As SBTool was considered as the most comprehensive assessment method, it has been customised for the Hong Kong context. A survey and an in-depth interview were used to bridge the gap between the Hong Kong context and the SBTool philosophy. However, the adaptation of such methods should involve systematic approaches, as reliance on one single tool may result in shortcomings. Hence it is argued that the starting point for developing a new method should involve a comparison between well-known methods [39].

Recently, Alyami and Rezgui [37] conducted a critical and comparative analysis of well known methods (BREEAM, LEED, SBTOOL and CASBEE); this was the first stage toward developing a Saudi Arabian environmental assessment method. This study identified areas of similarities and differences using a comparative approach. It concluded that a number of key building categories were not covered by leading methods (BREEAM and LEED), including: Economic and Social aspects; Building Quality of Services. More importantly, it highlights that the robust development of such a method would rely on (a) experts' consensus on applicable building assessment categories and criteria and (b) allocation of an applicable weighting system. This is owing to the fact that each region has its own individual specifications in terms of environmental, ecological and socio-cultural variations.

The overarching analysis of the development of a new environmental assessment method is that it should be based on qualitative approaches [39]. Furthermore, Ding [73] argues that sustainable assessment methods involve a spectrum of criteria; using a single-dimension approach is not a valid method of meeting the desired objective of sustainable development. Instead, a multi-dimensional approach that involves the participation of key stakeholders and decision makers provides a robust methodology for forming both quantitative and qualitative building assessment criteria.

Almost all environmental and sustainable assessment schemes have been designed to suit a specific territory [18]. Evidence suggests that existing sustainable assessment schemes were initially developed for local purposes, and are not fully applicable to all geographical regions [18,38]. More specifically, certain environmental factors can potentially hinder the use of existing sustainable assessment schemes. These factors may include climatic conditions, geographical characteristics, potential for renewable energy gain, resource consumption (such as water and energy), construction materials with associated techniques, and appreciation of historic and cultural values [12,14,40,41].

On the other hand, the environmental assessment of the interaction between buildings and the environment is still a subject of debate [26,39,40]. The authors argue that a consensus-based process is the most reliable approach for the delivery of a yardstick tool capable of identifying the impact of buildings on the environment [14]. Delphi is a consultation technique designed to deal with complex issues [27,42]. The development stages are illustrated in Fig. 1, and involve:

- ***Criteria identification*:** it is generally held that a comparison of the most reliable environmental assessment methods highlights areas of convergence and distinction. This is a potentially viable starting point in developing a new sustainable assessment scheme, through the generation and consolidation of existing environmental criteria [39].
- ***Regional variations Analysis*:** It is important to identify the unique characteristics of a region, in terms of potential resources, as well as economic and social specificities [41].
- ***Appointment of panel of experts*:** Expert opinion should be selected and acquired from a range of different fields, such as government, academia and industry [38].
- ***Conduct of Delphi technique*:** Given that sustainable assessment schemes are considered to be multi-dimensional [17], evidence suggests that a consensus based process is the most suitable means of developing a comprehensive and effective building environmental assessment criteria [26]. Therefore, three successive consultation rounds as shown below Fig. 1 have been conducted.

4. The Delphi consultation planning

Pre-investigation and informal interviews have been undertaken prior to the conduct of the Delphi process. This includes, visits paid to a number of different institutions, including: King Abdul-Aziz City for Science and Technology (KACST), Sustainable Energy Technology Centre (SETC), King Saud University, Saudi Environmental Society (SENS), Saudi Green Building Council (SGBC), Riyadh Municipality and Saudi Oger Ltd.

Furthermore, the main author attended two important gatherings of experts' events in Saudi Arabia, namely: the Environmental Infrastructure Forum in January 2012 and the Gulf Environmental

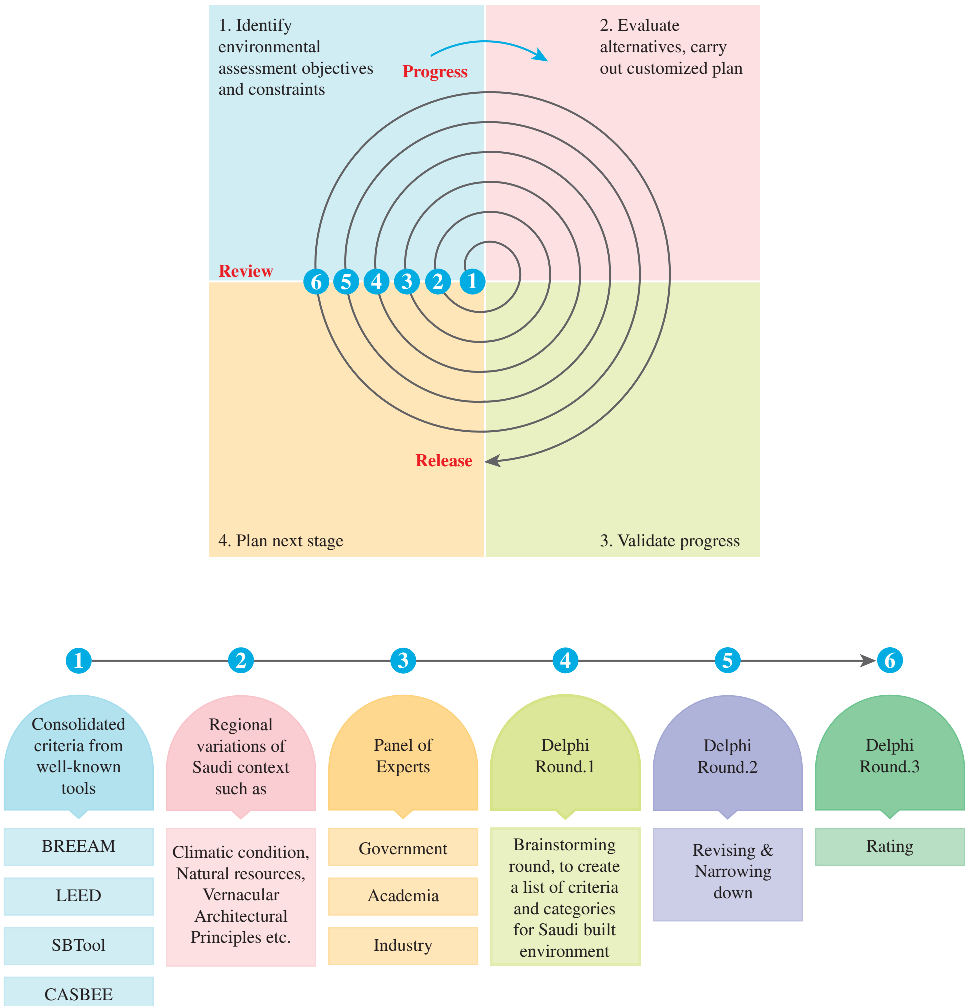


Fig. 1. Theoretical model for the development of Saudi building assessment scheme.

Forum in March 2012. The purpose of this “pre-investigation” was to inform (a) the research regarding the current practice of building assessment methods in Saudi Arabia, and then (b) the selection and nomination of potential experts.

Delphi technique can be conducted in a number of different ways [31,33,43]. However, this study is based upon the use of ***ranking Delphi***, which is nowadays the most commonly used technique [44]. The ranking technique draws its robustness from the four fundamental characteristics of Delphi, including: “*Anonymity*, *Iteration*, *Controlled feedback and Statistical group response*” [45]. The following sections will describe the Delphi consultation stages in this study.

4.1. Selection of the Delphi panel

The selection of the panel is a crucial element of a successful Delphi study [46–48]. Therefore, guidelines have been followed to ensure the suitability of panel in terms of both size and composition [28,42,49]. The number of experts in a Delphi panel can vary from 10 to 50 members, with the primary consideration being that the panel should be sufficiently large to allow the patterns of responses to be clearly seen; without being so large that complication and dissent becomes more likely [49,50]. Dalkey and Helmer [28] argue that research should not put statistical emphasis on the size of a panel, because this issue is not important to the Delphi technique. Instead, the main objective should be to select panellists with the capability, knowledge, professional qualifications and relevant experience in the field under investigation [51]. Therefore, the Delphi panel in this study comprises “thirty-three” members, including some of the world's leading experts in the domain of sustainable and environmental assessment schemes, as well as professionals and highly-informed local experts from academia, government and industry (see Table 1 below for panel composition). The selection of Delphi experts was guided by the following recommended criteria:

- Academic specialist in the area of Sustainable Development (SD).
- Decision-maker, manager, or practitioner in the field of sustainable and green building.
- Accredited professional in one of the leading sustainable assessment systems.
- Practical experience and sufficient knowledge of the sustainable development potential within the kingdom of Saudi Arabia.
- Expert with a level of influence regarding the adoption of the resulting methodology.
- Willingness to participate.

4.2. Development of the Delphi questionnaire

The questionnaire is designed to allow the experts to offer their judgements, with space provided for them to add, remove, criticise and justify their responses. Additionally, a pre-test pilot study was distributed to seven academic professionals prior to the Delphi

survey rounds, and their comments used to improve the quality and clarity of the survey. As a starting point for the Delphi survey, potential criteria have been consolidated from a comparative study of well-known schemes (e.g. BREEAM, LEED) [52]. These consolidated criteria have been designed in questionnaire format (following a *5 point Likert-type scale*), ranked from "*Not applicable*" to "*Very important*". This approach seeks to determine the appropriateness of these consolidated criteria for Saudi built environment. The followed section is a brief explanation of Delphi rounds in this study; which was the main source of data collection.

4.3. Data collection process

The Delphi questionnaire was designed and administered using a web based survey "Survey Monkey" (http://www.surveymonkey.com/). This software tool was extremely effective, enabling collection of the entire data within 4 months in three separate rounds.

- The first round sought to create a list of sustainable building assessment criteria, that are applicable to the Saudi Arabia built environment. This was based upon brainstorming process, with open-ended solicitation of criteria, in an attempt to obtain and clarify the key sustainable criteria for the Saudi context.
- The second round allowed the Delphi panellists to anonymously view the responses and feedback from the first round. This gave them the opportunity to revise their previous thoughts and reassess their initial judgements; within a Delphi study, the results of any previous iteration, whether specific statements or criteria can be changed or modified by individual panel members in later versions [31].
- The third round summarised the outcomes of the previous rounds, reflecting the opinion of the experts in the form of "*Statistical group response*" (Mean/Median). The survey was then sent again to the Delphi panel, to invite their final judgement; as this approach generally leads to improved judgements and increased overall accuracy [48,53].

4.4. Data analysis

Each round of the Delphi questionnaires was followed by an analytical stage, in which the feedback and the perspective of experts were presented to all participants. The medians and interquartile ranges (IQRs) were computed and utilised as a measurement of the overall level of agreement [31]. More detail on this stage will be presented in the following section.

5. Results

The main components of the building environmental and sustainable assessment scheme are generally divided into three hierarchical levels: Goal, Categories and Criteria [20,38]. While the existing methods share almost the same goal, each method is based upon its own philosophy for the allocation of categories and criteria. Since the aim of this study is to establish the most applicable building environmental and sustainable assessment categories and criteria for the Saudi Arabia built environment. Many exclusive criteria and new major categories have been developed by this study, as will be discussed below. The main results of this study are presented as follows: the framework of Saudi Arabia sustainable assessment scheme, the applicable criteria for the Saudi Arabia built environment, the overall rating of the sustainable assessment categories, and measurement of consensus.

5.1. The framework of Saudi Arabia building assessment scheme

The framework (Fig. 2) has been built upon the consensus amongst Delphi panel, with the core of this scheme being the promotion of sustainable development (SD) in the building sector. This framework illustrates three hierarchy levels; the first level includes four major dimensions: environmental, economic, social and management & innovation. The second level includes 11 key categories of building assessment. The third level includes 92 applicable criteria for the assessment of the built environment in Saudi Arabia.

5.2. The applicable criteria for the Saudi Arabia built environment

The criteria set out by the Delphi panellists are illustrated below.

5.2.1. Indoor environment quality

The indoor environment quality includes 15 criteria (as illustrated in Fig. 3) for ensuring the health and wellbeing of the occupant. For example, due to the extreme heat and dust in Saudi Arabia, mechanical ventilation is arguably more important than natural ventilation. Furthermore, the air tightness of building, for the protection of the occupant in the event of a sand storm, was deemed to be the most important criterion.

5.2.2. Energy efficiency

The criteria set out below (in Fig. 4) recognise the importance of taking the advantages from solar radiation while simultaneously delivering protection to ensure the provision of a comfortable and energy efficient building. In this regard, building envelope performance and shading strategies were considered of the highest importance, in addition to the HVAC system and sub-metering of electricity use. Furthermore, renewable energy technology was also a core consideration, promoting the use of greener products such as PV panels.

5.2.3. Water efficiency

It is clear from the water efficiency criteria (Fig. 5) that water consumption and conservation strategies were deemed to be extremely significant for Saudi context. Furthermore, strategies such as *grey water recycling*, *rain water harvesting and suitability of water restriction level* are also viable ways of reducing the overall water consumption.

5.2.4. Waste management

The waste management criteria (Fig. 6) show that modern methods of construction, such as off-site assembly and recycling facilities, can play an important role in waste reduction. Hence, the panellists agreeing that waste management is the most important criterion. In the early stage of this study, one expert suggested considering *the principles of designing out waste rather than dealing with waste created*, which was later accepted as one of the criteria in this framework.

5.2.5. Pollution

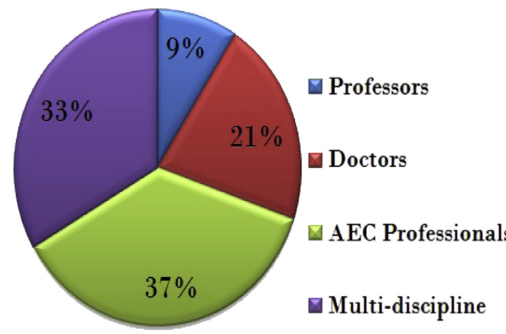
It is clear that the 9 criteria related to pollution (Fig. 7) were all rated as being very important. The most important of these considerations are pollution due to natural disaster, flooding, fire risk and CO_2 emissions. In addition, the Delphi panel agreed that the protection from sand storms is a unique criterion, particularly relevant for building in the Arab peninsula.

5.2.6. Management

A total of 9 criteria (Fig. 8) for management and innovation were revised and rated by the Delphi panel. The management of

Table 1
Background of Delphi panellists.

Experts	Organisation	Panel distributions
International	BRE: Building Research Establishment Arup Perren Partners & Cardiff University	
Official government	KACST: King Abdul-Aziz City for Science and Technology SEEC: Saudi Energy Efficiency Centre Riyadh Municipality	
Academia	King Saund University Cairo University	
Industry	Saudi Aramco Saudi Orger Zuhair Fayez Partnership Arab Engineering Bureau Saudi Green Building Council Middle East Centre for Sustainable Development Aljabreen Contracting Company DEC Consultants Arab Contractor ETA Engineering & Contracting Saudi Diyar Consulting PMDC: Engineering SolutionsConsultancy Nakheel Company	



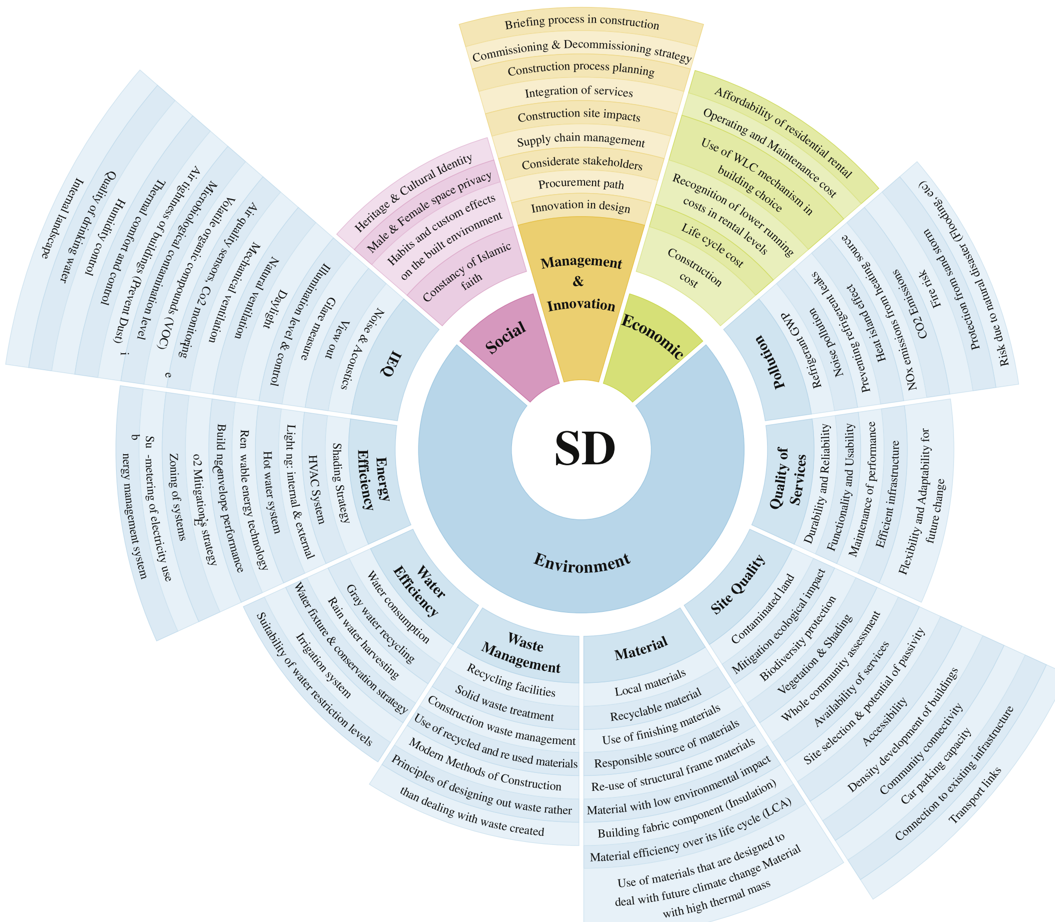


Fig. 2. Framework of Saudi Arabia building assessment scheme.

the construction process and the integration of services were deemed to be the most important consideration, although innovations in design and construction site impact were given almost the same level of importance.

5.2.7. *Site quality*

The Delphi panel agreed that the quality of the built area is associated with its surrounding local services, civil construction network and the location of building itself. Hence, the 13 criteria

Indoor Environment Quality
1. Noise & Acoustics control
2. View out
3. Glare measure & control
4. Illumination level & control
5. Daylight
6. Natural ventilation
7. Mechanical ventilation
8. Air quality sensors- CO2 Monitoring
9. Volatile organic compounds (VOC)
10. Microbiological contamination level
11. Air tightness of buildings(Prevent Dust)
12. Thermal comfort and control
13. Humidity control
14. Quality of drinking water
15. Internal landscape(Vegetation)

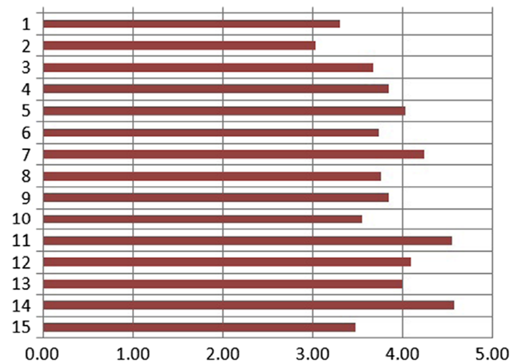


Fig. 3. Indoor environment quality criteria.

Energy Efficiency
1. Building envelope performance
2. HVAC System
3. Lighting: internal & external
4. Hot water system
5. Renewable energy technology
6. Shading Strategy
7. Co2 Mitigations strategy
8. Zoning of systems
9. Sub-metering of electricity use
10. Energy management system

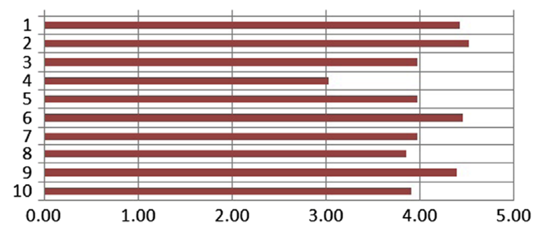


Fig. 4. Energy efficiency criteria.

below (Fig. 9) encourage green and sustainable practices; seeking the potential of "*Passivity*" in the selection of a site. They also promote building density development and community connectivity, whilst ensuring that buildings are adequately connected to basic infrastructure and local services.

5.2.8. *Material*

The below figure illustrates (see Fig. 10) that the choice of "*materials with low environmental impact*" along with "*building fabric components*" are the most important considerations. The Delphi panel also agreed that the use of materials that are designed to address future climate change issues is a key criterion for Saudi context. The overall objective of these criteria is to avoid harmful practices in building material production as well as to enhance energy efficient design.

5.2.9. *Quality of services*

The quality of services criteria requires the evaluation of key aspects of the building's performance, such as the degree of its functionality, usability, durability and reliability. The most important consideration was deemed to be efficiency of infrastructure (as illustrated in Fig. 11).

5.2.10. *Economic aspects*

While the economic aspect of a build is a fundamental aspect of sustainable development, the extent to which this is overlooked by leading international schemes is surprising. The results of the deliberation process for this study generated 6 important criteria (see Fig. 12) for the evaluation of the overall life cycle costs of buildings. Certain of the panel stressed that the use of a whole life costing (WLC) mechanisms is a robust and sustainable practice.

5.2.11. *Cultural aspects*

The social life of Saudi Arabian people has a remarkable effect on shaping their building designs. Therefore, the 4 criteria shown in (Fig. 13) are the socio-cultural criteria that identified by this study. These criteria will evaluate certain requirements, from building design, that are required in order to meet the choices and desires of occupants.

5.3. *Overall ranking of the assessment categories*

All categories illustrated below (see Fig. 14) are essential, and presented here based on their level of importance. This, in turn, provides a clear picture to the building stakeholders regarding the prioritisation of these categories for Saudi context.

The judgement of the panel is that water efficiency is the top priority. Subsequently, energy efficiency design and indoor environmental quality are almost at the same level. This agreement by the Delphi panel about the prioritisation of the above three categories are compatible with current concerns in relation to the Saudi Arabian built environment: water use challenges; renewable energy potential (especially solar energy); and poor indoor environmental design [54–56].

The next most important priorities include waste management, pollution and general management and innovation. These categories are closely linked. For example, the criterion for *Recycling facilities* from the waste management category can also reduce pollution, as well as reflecting the commissioning and stakeholder strategy of managing the built environment.

Eventually, site quality; material; quality of services; economic; and cultural aspects achieved almost the same level of importance. These criteria, as agreed by all panellists, are essential for the creation of a coherent and comprehensive scheme to evaluate the requirements of Saudi Arabia's built environment.

5.4. *Consensus measurement*

It has been claimed that the four characteristics of the Delphi technique (anonymity; iteration; controlled feedback; and

Water Efficiency
1. Water consumption
2. Grey water recycling
3. Rain water harvesting
4. Water fixture & conservation strategy
5. Irrigation system
6. suitability of water restriction levels

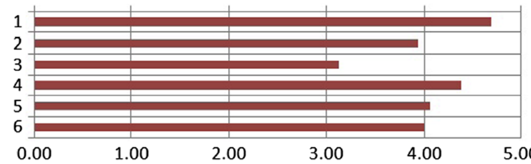


Fig. 5. Water efficiency criteria.

Waste Management
1. Construction waste management
2. Solid waste treatment
3. Recycling facilities
4. Modern Methods of Construction i.e. off-site assembly
5. Use of recycled and re used materials
6. Principles of designing out waste rather than dealing with waste created

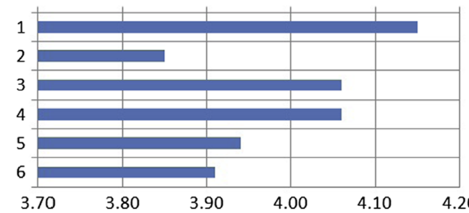


Fig. 6. Waste management criteria.

Pollution
1. Refrigerant GWP – Building services
2. Night light and noise pollution
3. Preventing refrigerant leaks
4. Heat island effect
5. NOx emissions from heating source
6. CO2 Emissions
7. Fire risk
8. Risk due to natural disaster (Flooding, etc)
9. Protection from sand storm

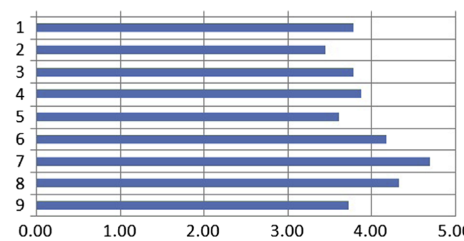


Fig. 7. Pollution criteria.

Management
1. Commissioning & Decommissioning strategy
2. Procurement path
3. Construction process planning
4. Briefing process in construction
5. Considerate stakeholders
6. Supply chain management
7. Construction site impacts
8. Integration of services
9. Innovation in design

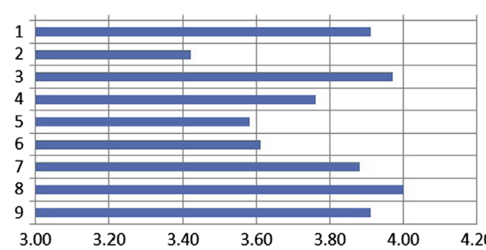


Fig. 8. Management criteria.

Site Quality
1. Site selection & potential of passivity
2. Contaminated land
3. Mitigation ecological impact
4. Biodiversity protection
5. Vegetation & Shading
6. Accessibility
7. Density development of buildings
8. Community connectivity
9. Car parking capacity
10. Connection to existing infrastructure
11. Whole community assessment
12. Availability of services
13. Transport links

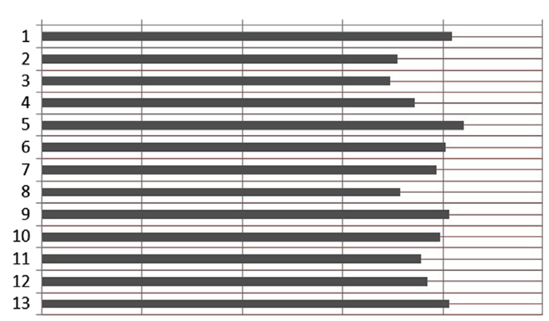


Fig. 9. Site quality criteria.

statistical "group response") are instrumental in achieving stability and consensus [53]. A number of different qualitative analysis methods exist for measuring this consensus; the approach chosen in this study, interquartile range (IQR), is a descriptive statistical method that examines each mean of consensus [33]. The value of the IQR is dependent on the unit scales; for example, for 5-unit Likert scales consensus is indicated by values of IQR between 0 and 1($0 < IQR < 1$) [53]. Table 2 illustrates the status of consensus from

Material
1. Material with low environmental impact
2. Local materials
3. Recyclable material
4. Re-use of structural frame materials
5. Building fabric component (Insulation)
6. Responsible source of materials
7. Use of finishing materials
8. Material efficiency over its life cycle (LCA)
9. Use of materials that are designed to deal with future climate change
10. Material with high thermal mass

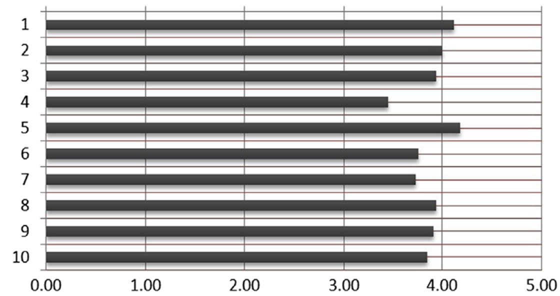


Fig. 10. Material criteria.

Quality of Services
1. Functionality and Usability
2. Flexibility and Adaptability for future change
3. Durability and Reliability
4. Maintenance of performance
5. Efficient infrastructure

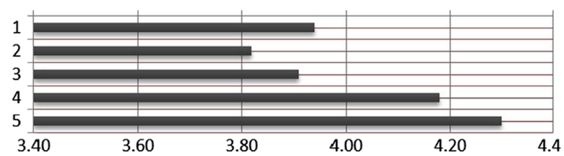


Fig. 11. Quality of services criteria.

Economic Aspects
1. Construction cost
2. Life cycle cost
3. Operating and Maintenance cost
4. Affordability of residential rental
5. Use of whole life costing mechanism in building choice
6. Recognition of lower running costs in rental levels

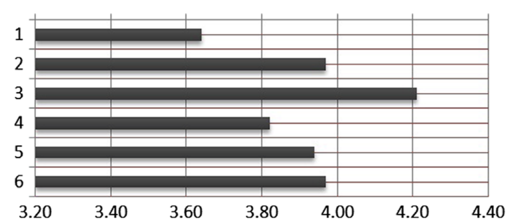


Fig. 12. Economic aspects criteria.

Cultural Aspects
1. Heritage & Cultural Identity
2. Male & Female space privacy
3. Habits and custom effects on the built environment
4. Constancy of Islamic faith

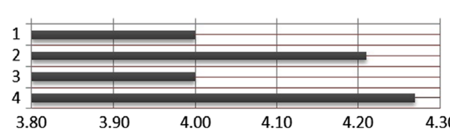


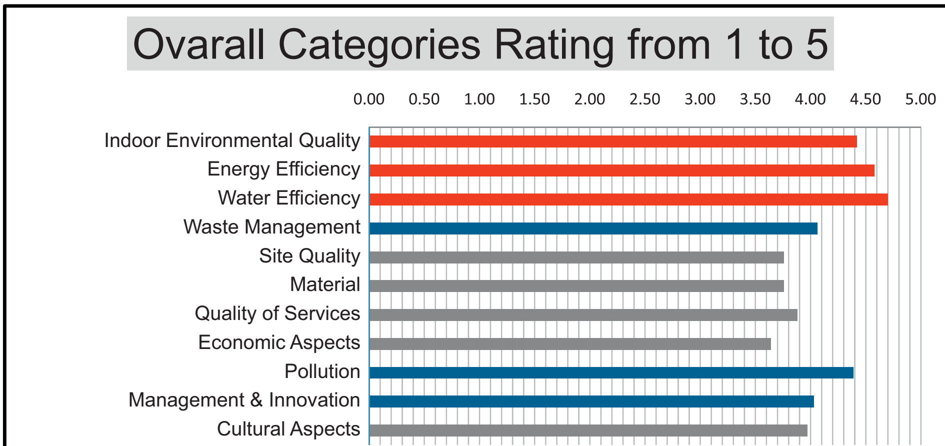
Fig. 13. Cultural aspects criteria.

the final Delphi round, which clearly demonstrating agreement among the Delphi panel.

6. Discussion

Renewable energy technology provides a solid foundation to promote clean energy generation and hence a more sustainable built environment. Saudi Arabia enjoys as a country wide exposure to solar energy across all its regions. Moreover, the average annual solar energy in Saudi Arabia is in excess of 2200 kWh/m^2, which can be considered as relatively high when compared to other countries' solar potential [55]. Environmentally, for each gigawatt-hour of electricity generated by solar PV, a large amount of hazardous emissions would be prevented, including up to 1000 t of carbon dioxide, 4 t of nitrogen oxides, 0.7 t of particulates and 10 t of sulphur dioxide [57]. Yet some solar PV modules consist of hazardous materials (tellurium, cadmium, lead and selenium). These compounds have severe impacts on wildlife, including Saudi Fauna and flora; also, they may affect humans' health and well-being via the food chain [58]. Improving government regulation of those hazards is one major way to tackle this issue. Germany's experience provides standing evidence in this area; it has imposed a set of regulations for recycling electronic waste [58]. The regulated decommissioning of PV waste is a key consideration for the Saudi future plan.

In addition, there is potential for alternative sources of renewable energy (other than PV) in Saudi Arabia. Alnatheer [59] highlights various forms of environmentally and economically competitive energy sources, including solar thermal, wind energy, and geothermal energy. Solar thermal involves different systems of electricity generation, such as power towers, parabolic troughs, and dish/engine. The sun's radiation consternated onto a heat absorber produces steam and thereby generates electricity. This



	Cultural Aspects	Management & Innovation	Pollution	Economic Aspects	Quality of Services	Material	Site Quality	Waste Management	Water Efficiency	Energy Efficiency	Indoor Environmental Quality
Mean	3.97	4.03	4.39	3.64	3.88	3.76	3.76	4.06	4.70	4.58	4.42

Fig. 14. Overall importance scale.

technology is used to supply thermal energy for both heating and cooling systems. This, therefore, has the potential to enhance clean energy generation in Saudi Arabia as the country experiences high demands for cooling, representing a major source of overall energy consumption [6]. As for wind energy, Al-Abbadi [60] reveal through their study that the highest average annual wind speed is 5.7 m/s for about 60% of the time. The estimated energy generated from this wind speed can reach up to 1080 MWh.

Saudi Arabia has an interesting potential for geothermal energy. Rehman and Shash [61], state that Saudi Arabia has ten hot springs discovered in the southern province of the country (*Gizan and Al Lith regions*). Moreover, a geological inspection was recently carried out as a result of which large volcanic areas were discovered in the Western region. However, given the economical competitive energy market, geothermal energy remains an untapped source of renewable energy [62]. Out of the above renewable generation sources, PV remains in a short to medium timescale the main viable technology at a domestic level. This is currently enjoying relatively wide acceptance and uptake.

Leading schemes, such as BREEAM and LEED, have been critically revised in the development of the assessment scheme for Saudi Arabia. However, regional and cultural variations in Saudi Arabia support the further development of suitable categories and criteria. Throughout the Delphi study, a clear consensus has been reached; that a number of categories and criteria have not been recognised, by leading schemes, as central dimensions for Saudi context. Hence, this study develops a comprehensive framework to assess Saudi Arabia's built environment. The following points identify categories and key criteria that have been, to some extent, over-looked by international schemes:

- **Climatic conditions of Saudi Arabia:** The typical climate of Saudi Arabia requires designers and builders to observe certain considerations. As an illustration of this, heavy sandstorms are a common phenomenon in the Arabian Peninsula [63], with a severe impact on inhabited cities, causing health problems and communication disruption [64]. Therefore, the Delphi panel recognise the need for criteria that can enhance the quality of the indoor environment, in particular in the context of sandstorms. These criteria include: ***Air tightness of buildings*** **(*as an effective barrier to dust*), and *Internal landscaping*** **(*Vegetation*).** Another example of the Saudi Arabian situation is that the clear skies and extremely hot arid weather significantly increase building exposure to bright sunlight, meaning that ***shading strategies*** should be used to protect building envelopes and occupants from solar radiation. The shading strategy can also play an important role in energy saving and enhancing the comfort of the indoor environment [65,66]. In addition, due to climate change and global warming indicators in the middle east [56,67], the panellists agreed that the degree of ***building adaptability for future change*** is significant, especially given evidence that predicts the temperature of Saudi Arabia will rise by approximately 2.0–2.75 °C in the next 30 years [68].
- **Natural resources (Energy, Water, and Material):** It is estimated that about two-thirds of the electricity generated in Saudi Arabia is used in buildings [7]. Current practices involve burning fossil fuel to produce heavily subsidised electricity and water, resulting in a lack of awareness about environmental concerns. This, in turn, create a barrier to the widespread adoption of sustainable architecture in Saudi Arabia [6]. In recognition of sustainable energy being one of the objectives of the Saudi Arabian building assessment framework, the panel recommend the promotion of one of the highest potential renewable energy sources, s***olar energy application***, coupled with relevant building fabric and shape design.
As the Kingdom is not densely populated, electrification and desalination plants, along with other basic networks have been expanded over thousands of kilometres to cover the most populated cities [7]. However, certain rural and remote areas are not yet connected to the network, and connecting them will require an additional increase in power generation [8]. Therefore, various criteria were recommended to manage this expansion, including: ***Renewable energy technology and, Sub-metering of electricity use***.
Saudi Arabia has poor water resources and is heavily dependent on non-renewable resources such as groundwater and sea water treatment (desalination) [6,54]. This study ranked water as the top priority category, with the aim of raising awareness amongst utility customers regarding water scarcity. Therefore, the panellists recommended encouraging innovative strategy

Table 2
Consensus calculation using interquartile range (IQR).

Categories	Number of criteria	IQR	Status of consensus
Indoor environment quality	15	0.4500	✓ Achieved
Energy efficiency	10	0.4875	✓ Achieved
Water efficiency	6	0.3525	✓ Achieved
Waste management	6	0.1425	✓ Achieved
Site quality	13	0.3300	✓ Achieved
Material	9	0.2025	✓ Achieved
Quality of services	5	0.2700	✓ Achieved
Economic aspects	6	0.1200	✓ Achieved
Pollution	9	0.4500	✓ Achieved
Management and innovation	9	0.3000	✓ Achieved
Cultural aspects	4	0.2250	✓ Achieved

of water conservatives and ***Ensuring that the restriction level of water supply should not lead to unsustainable practices***. Building material requires large amount of embodied energy that also put intensive pressure on the natural environment [69]. However, The Delphi panel add that buildings should be ***designed to deal with future climate change***, using ***environmentally friendly material with high thermal mass*** that can cope with the environmental and climatic conditions of Saudi Arabia.

- **Infrastructure (building services):** The evaluation of building performance alone is not an efficient way of realising sustainable development goals, as building operations depend on various networks and infrastructures. However, international assessment schemes assume the existence of a coherent infrastructure, such as water, sewage, drainage systems and transportation networks. The reality for developing countries is that these basic infrastructure and services are incomplete or insufficient. Therefore the panel have highlighted the importance of ***promoting efficiency in infrastructure and connecting the building to it***, thereby not only improving the quality of the building sector but also nearby communities.
  Furthermore, torrential rainfall in Saudi Arabia is a dramatic phenomena that causes massive flooding, pollution, and even loss of life and property (e.g. Jeddah flooding, 2009) [63]. For this reason, ***Pollution and risk due to flooding*** are considered as key criteria in the assessment of Saudi's built environment, with the aim of recognising these threats and creating built environments that can thrive without external risks.
- **Economic aspects:** Financial considerations are essential in sustainability development in both developed and developing countries. Developed countries are concerned with the reduction of environmental impact while maintaining standards of living [39], while in developing countries economic and social issues are often as important as environmental considerations [70]. However, neither BREEAM nor LEED consider financial aspects in their evaluative framework, this arguably contradicting the ultimate principle of sustainable development, as financial returns are essential for all projects, with environmentally friendly projects potentially being very expensive to build [17]. Therefore, this scheme has incorporated economic criteria that play an important role in Saudi Arabia's built environment, including ***Use of whole life costing mechanism in building choice (WLC), Affordability of residential rental, and constructions cost & pay back***.
- **Cultural aspects:** Residential buildings in Saudi Arabia are greatly influenced by cultural considerations. Typical Saudi families are large and dynamic, keeping strong ties with even distant relatives and neighbours. Therefore, buildings need to be designed and built to accommodate social events and needs. This issue was raised by various local experts in the consultation rounds. A consensus was reached by the Delphi panel in the subsequent rounds. The required criteria for the assessment of residential buildings include: ***Male and Female space privacy; Heritage and Cultural Identity; Habits and custom effects on the built environment and; Constancy of Islamic faith***. These issues are completely overlooked by the leading international schemes, which also contradict sustainable development principles.
- ***Construction Management:*** There are many manageable parameters that can indirectly impact upon the quality of the built environment. For this reason, BREEAM stipulates the fundamental criteria for sustainable management principles [20]. However, a number of additional criteria have been incorporated into the Saudi scheme; in order to take ***supply chain management*** into account, as well as the ***briefing process in construction*** and the ***integration of services***. The application of these aspects will boost the adoption of best practices and sustainable development principles in the building sector in Saudi Arabia.

7. Conclusion

Saudi Arabia has a high potential for renewable energy and therefore the promotion of sustainability developments [71]. This means that it is crucially important to design and implement a yardstick scheme to evaluate the principles of sustainable construction, thereby encouraging the widespread adoption of sustainable energy and recognition of green building principles. An overarching hypothesis has been set to meet this objective, namely that the leading international sustainable assessment schemes, such as BREEAM and LEED, are unsuitable for the Saudi Arabia built environment. This hypothesis was tested using the Delphi technique, over a four month period. Thirty three Delphi panellists have reached a consensus on the applicable categories and criteria for a sustainable building assessment scheme in Saudi Arabia.

The findings of this consultation process strongly suggest that international schemes such as BREEAM and LEED are inapplicable for the Saudi context. Hence, there is a need to develop further categories and criteria for the assessment of the built environment in Saudi Arabia. Expert consensus converge in that building environmental and sustainable assessment categories should include: *indoor environmental quality*, *energy efficiency*, *water efficiency*, *waste management*, *site quality*, *material*, *pollution*, *quality of services*, *economic aspects Cultural aspects and Management and Innovation*. Each of the above categories includes a list of related criteria (shows in Fig. 3 in the proposed Framework), creating a 92 item list of criteria for sustainable residential building assessment in Saudi Arabia.

Due to the absence of a non-subjective approach for the development of new weighting systems for sustainable assessment schemes, the use of *Analytical Hierarchy Process* (*AHP*) considers a viable alternative [24,72]. This constitutes follow on future work which will deliver a weighting system for the generated categories and criteria, identified and approved with the use of the Delphi technique. This will be reported in follow on publications.

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